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(54) **METHODS AND APPARATUS FOR REDUCING GAS TURBINE ENGINE EMISSIONS**

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F02C 3/30 (2006.01)

(52) **U.S. Cl.** **60/775**; 60/39.55; 60/737; 60/747

(58) **Field of Classification Search** 60/39.05, 60/39.55, 737, 747, 775
See application file for complete search history.

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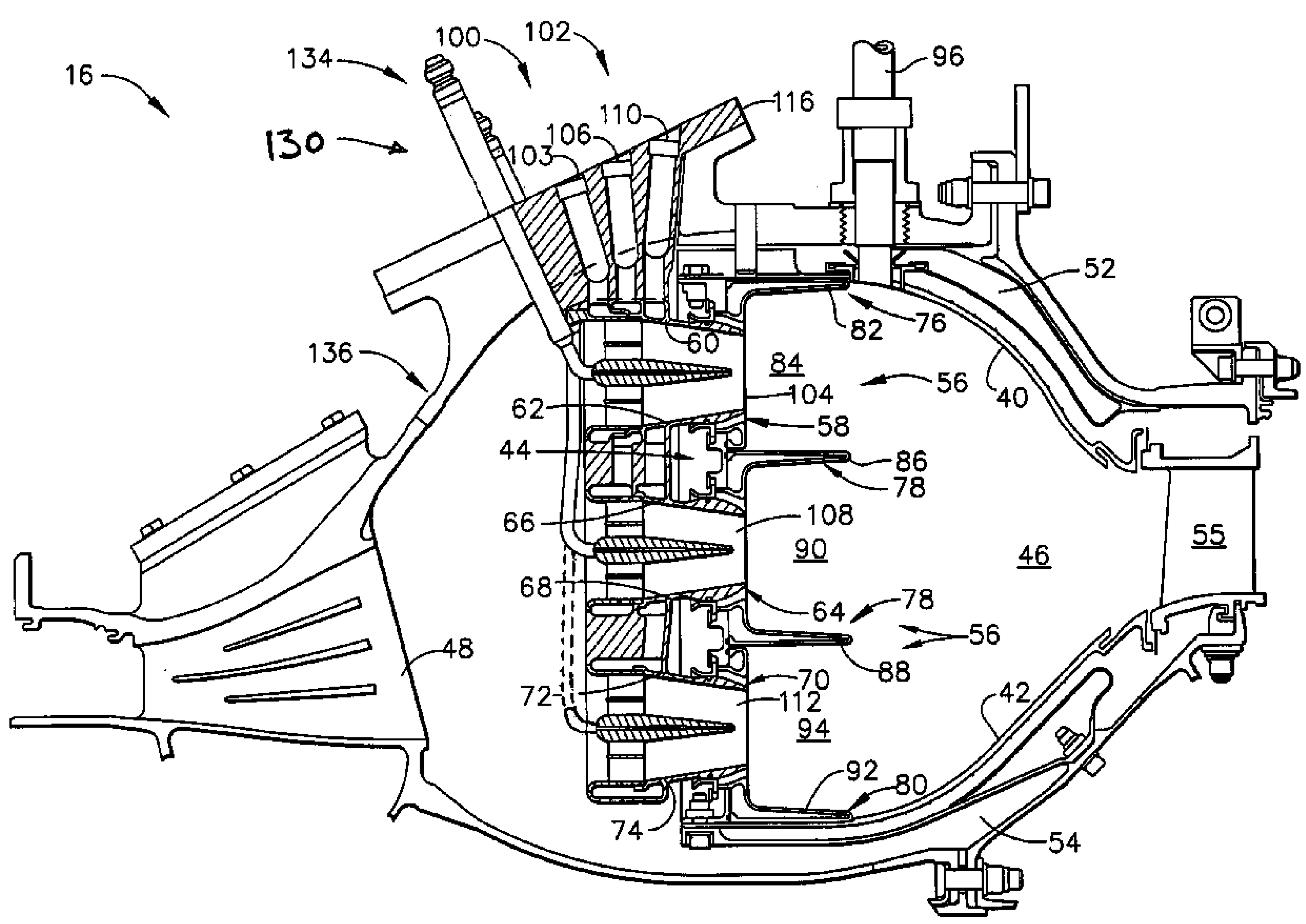
(57) **ABSTRACT**

A gas turbine engine includes a combustor system including a lean premix combustor and a water delivery system. The combustor is operable with a fuel/air mixture equivalence ratio less than one and the water delivery system is configured to supply at least one of water or steam to the gas turbine engine such that either the water or the steam is injected into the combustor to control emissions generated by the combustor. As a result, nitrous oxide emissions for specified turbine operating power levels are lowered.

19 Claims, 2 Drawing Sheets



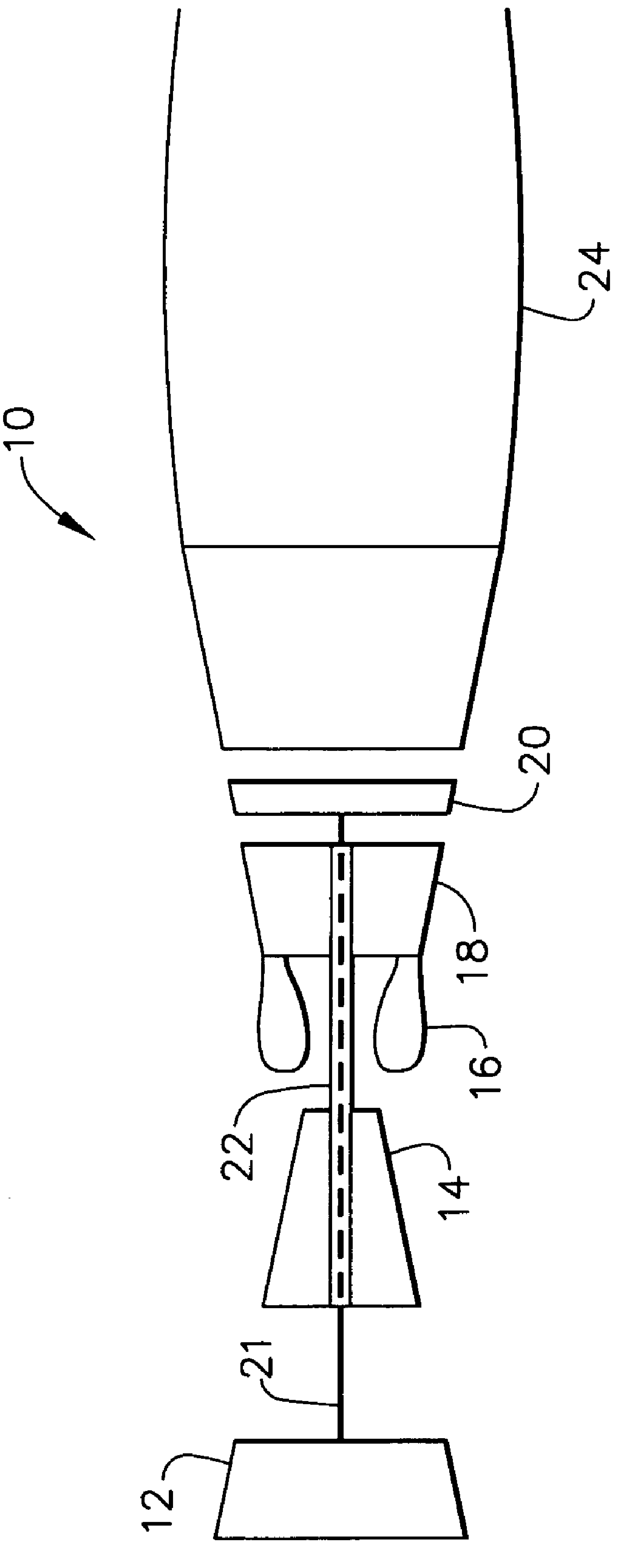


FIG. 1

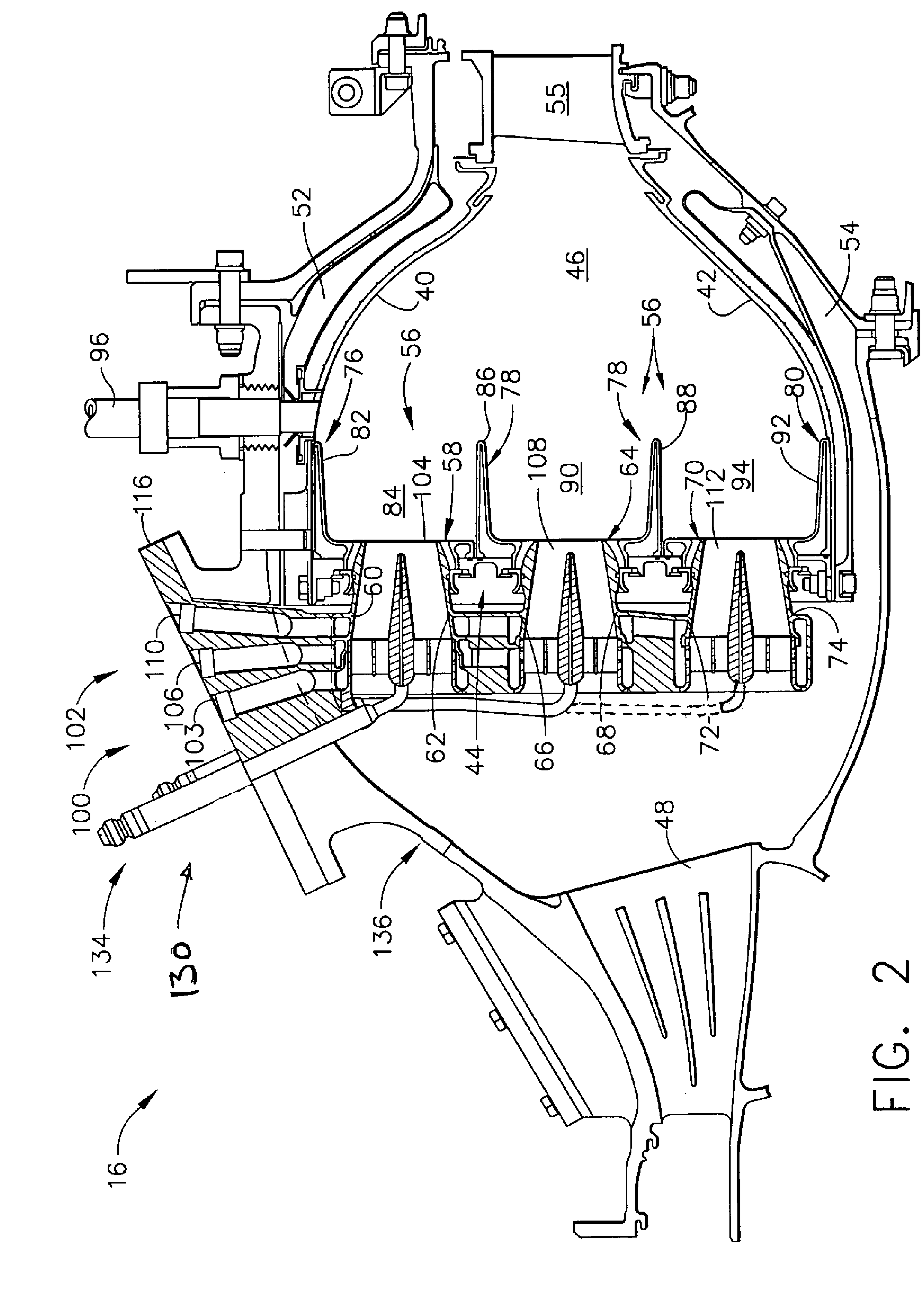

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FIG. 2

METHODS AND APPARATUS FOR REDUCING GAS TURBINE ENGINE EMISSIONS

BACKGROUND OF THE INVENTION

This application relates generally to gas turbine engines and, more particularly, to combustors for gas turbine engine.

Air pollution concerns worldwide have led to stricter emissions standards. These standards regulate the emission of oxides of nitrogen (NOx), unburned hydrocarbons (HC), and carbon monoxide (CO) generated as a result of gas turbine engine operation. In particular, nitrogen oxide is formed within a gas turbine engine as a result of high combustor flame temperatures. Making modifications to a gas turbine engine in an effort to reduce nitrous oxide emissions often has an adverse effect on operating performance levels of the associated gas turbine engine.

In gas turbine engines, nitrous oxide emissions can be reduced by increasing airflow through the gas turbine combustor during operating conditions. Gas turbine engines include preset operating parameters and any such airflow increases are limited by the preset operating parameters including turbine nozzle cooling parameters. As a result, to increase the airflow within the gas turbine combustor, the gas turbine engine and associated components should be modified to operate at new operating parameters.

Because such gas turbine engine modifications are labor-intensive and time-consuming, users are often limited to derating the operating power capability of the gas turbine engine and prevented from operating the gas turbine engine at full capacity. Such derates do not limit an amount of nitrous oxide formed as the engine operates at full capacity, but instead limit the operating capacity of the gas turbine engine.

BRIEF SUMMARY OF THE INVENTION

In an exemplary embodiment, a gas turbine engine includes a combustor system to reduce an amount of nitrous oxide emissions formed by the gas turbine engine. The combustor system includes a combustor and a fuel and water delivery system. The combustor is a lean premix combustor including a plurality of premixers and is operable with a fuel/air mixture equivalence ratio less than one. The water delivery system supplies at least one of water or steam to the gas turbine engine such that water or steam is injected into the combustor.

During normal gas turbine engine operations, fuel is supplied proportionally with airflow to the combustor such that the combustor operates with a fuel/air mixture equivalence ratio less than one. As gas turbine engine operating speeds increase and additional fuel and air are supplied to the combustor, the water delivery sub-system supplies either water or steam to the combustor. The increase in combustion zone flame temperatures generated as a result of additional fuel being burned within the combustor is minimized with the water or steam supplied to the combustor. As a result, nitrous oxide emissions generated are reduced. Alternatively, the gas turbine engine may achieve an increased operating power level for a specified nitrous oxide emission level.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. **1** is a schematic illustration of a gas turbine engine; and

FIG. **2** is a cross-sectional view of a combustor used with the gas turbine engine shown in FIG. **1**.

DETAILED DESCRIPTION OF THE INVENTION

FIG. **1** is a schematic illustration of a gas turbine engine **10** including a low pressure compressor **12**, a high pressure compressor **14**, and a combustor **16**. Engine **10** also includes a high pressure turbine **18** and a low pressure turbine **20**. Combustor **16** is a lean premix combustor. Compressor **12** and turbine **20** are coupled by a first shaft **21**, and compressor **14** and turbine **18** are coupled by a second shaft **22**. A load (not shown) is also coupled to gas turbine engine **10** with first shaft **21**. In one embodiment, gas turbine engine **10** is an LM6000 available from General Electric Aircraft Engines, Cincinnati, Ohio. Alternatively, gas turbine engine **10** is an LM 2500 available from General Electric Aircraft Engines, Cincinnati, Ohio.

In operation, air flows through low pressure compressor **12** and compressed air is supplied from low pressure compressor **12** to high pressure compressor **14**. The highly compressed air is delivered to combustor **16**. Airflow from combustor **16** drives turbines **18** and **20** and exits gas turbine engine **10** through a nozzle **24**.

FIG. **2** is a cross-sectional view of combustor **16** used in gas turbine engine **10** (shown in FIG. **1**). Because combustor **16** is a lean premix combustor, a fuel/air mixture supplied to combustor **16** contains more air than is required to fully combust the fuel. Accordingly, a fuel/air mixture equivalence ratio for combustor **16** is less than one. Because combustor **16** premixes fuel with air, combustor **16** is a lean premix combustor. Combustor **16** includes an annular outer liner **40**, an annular inner liner **42**, and a domed end **44** extending between outer and inner liners **40** and **42**, respectively. Outer liner **40** and inner liner **42** are spaced radially inward from a combustor casing **136** and define a combustion chamber **46**. Combustor casing **136** is generally annular and extends downstream from a diffuser **48**. Combustion chamber **46** is generally annular in shape and is disposed radially inward from liners **40** and **42**. Outer liner **40** and combustor casing **136** define an outer passageway **52** and inner liner **42** and combustor casing **136** define an inner passageway **54**. Outer and inner liners **40** and **42** extend to a turbine nozzle **55** disposed downstream from diffuser **48**.

Combustor domed end **44** includes a plurality of domes **56** arranged in a triple annular configuration. Alternatively, combustor domed end **44** includes a double annular configuration. In another embodiment, combustor domed end **44** includes a single annular configuration. An outer dome **58** includes an outer end **60** fixedly attached to combustor outer liner **40** and an inner end **62** fixedly attached to a middle dome **64**. Middle dome **64** includes an outer end **66** attached to outer dome inner end **62** and an inner end **68** attached to an inner dome **70**. Accordingly, middle dome **64** is between outer and inner domes **58** and **70**, respectively. Inner dome **70** includes an inner end **72** attached to middle dome inner end **68** and an outer end **74** fixedly attached to combustor inner liner **42**.

Combustor domed end **44** also includes a outer dome heat shield **76**, a middle dome heat shield **78**, and an inner dome heat shield **80** to insulate each respective dome **58**, **64**, and **70** from flames burning in combustion chamber **46**. Outer dome heat shield **76** includes an annular endbody **82** to insulate combustor outer liner **40** from flames burning in an outer primary combustion zone **84**. Middle dome heat shield **78** includes annular centerbodies **86** and **88** to segregate middle dome **64** from outer and inner domes **58** and **70**, respectively. Middle dome centerbodies **86** and **88** are disposed radially outward from a middle primary combustion zone **90**. Inner dome heat shield **80** includes an annular endbody **92** to insulate combustor inner liner **42** from flames burning in an inner primary combustion zone **94**. An igniter **96** extends through combustor casing **136** and is disposed downstream from outer dome heat shield endbody **82**.

Domes **58**, **64**, and **70** are supplied fuel and air via a premixer and assembly manifold system (not shown). A plurality of fuel tubes **102** extend between a fuel source (not shown) and plurality of domes **56**. Specifically, an outer dome fuel tube **103** supplies fuel to a premixer cup **104** disposed within outer dome **58**, a middle dome fuel tube **106** supplies fuel to a premixer cup **108** disposed within middle dome **64**, and an inner dome fuel tube **110** supplies fuel to a premixer cup **112** disposed within inner dome **70**.

Combustor **16** also includes a water delivery system **130** to supply water to gas turbine engine **10** such that water is injected into combustor **16**. Water delivery system **130** includes a plurality of water injection nozzles **134** connected to a water source (not shown). Water injection nozzles **134** are in flow communication with premixer cups **104**, **108**, and **112** and inject an atomized water spray into the fuel/air mixture created in premixer cups **104**, **108**, and **112**. In an alternative embodiment, injection nozzles **134** are connected to a steam source (not shown) and steam is injected into the fuel/air mixture using nozzles **134**.

During operation of gas turbine engine **10**, air and fuel are mixed in premixer cups **104**, **108**, and **112** and the fuel/air mixture is directed into domes **58**, **64**, and **70**, respectively. The mixture burns in primary combustion zones **84**, **90**, and **94** of domes **58**, **64**, and **70** that are active. At high power gas turbine engine operations, fuel entering premixer cup **108** is increased, resulting in a higher fuel/air ratio within dome **64**.

Middle dome **64** is known as a pilot-dome and has fuel supplied thereto during all phases of operation of engine **10**. Domes **58** and **70** have fuel supplied thereto as demanded by operating power requirements of gas turbine engine **10**. As gas turbine engine operating power requirements are increased, water is also supplied to domes **58**, **64**, and **70**, as demanded to meet nitrous oxide emission requirements. Gas turbine engine **10** has a rated engine operating capacity. To operate gas turbine engine **10** above 90% rated engine operating capacity, additional fuel is supplied only to combustor middle dome **64**. During such engine power operations, water delivery system **130** supplies additional water to middle dome **64** to minimize temperature increases as a result of additional fuel being burned within combustor middle dome **64**.

More specifically, when gas turbine engine **10** is operated above approximately 90% rated engine power capacity, additional fuel is supplied only to combustor middle dome **64** because outer and inner dome flame temperatures are limited by dynamic pressure or acoustic boundaries. When gas turbine engine **10** is operating at such a capacity, water delivery system **130** supplies water to combustor **16** to maintain flame temperatures generated within middle dome **64** approximately equal to flame temperatures generated within outer and inner domes **58** and **70**. Furthermore, nitrous oxide emissions generated within middle dome **64** are maintained at a level approximately equal to those levels generated within outer and inner domes **58** and **70**. Additionally, by supplying additional water to only middle dome **64** during such engine operations, the potential adverse effects of generating additional carbon monoxide emissions within combustor **16** are offset by the reduction in nitrous oxide emissions and the increase in operating capacity. Alternatively, the operating power level of gas turbine engine **10** may be increased for a specified nitrous oxide emission level.

Similarly, as engine performance degrades over time, additional fuel is required to produce similar engine output in comparison to engines that have not deteriorated. For the reasons discussed above, additional fuel is supplied to combustor middle dome **64**. During such engine operations, water delivery system **130** supplies water at an increased flow rate to middle dome **64** to maintain the middle dome flame temperatures and to control the generation of emissions resulting from increased fuel flow.

In a further embodiment, water delivery system **130** is selectively operable between a first mode of operation and a second mode of operation. The first operating mode of water delivery system **130** is activated during all phases of operation of gas turbine engine **10** above engine idle operations. Typically, in the first operation mode, water delivery system **130** supplies water proportionally to all three domes **58**, **64**, and **70** at approximately the same rate.

The second operating mode of water delivery system **130** is activated when gas turbine engine **10** is operated above 90% rated engine operating capacity. When water delivery system **130** operates in the second operating mode, water is supplied to middle dome **64** at a higher flow rate than water supplied to dome **64** when water delivery system **130** is in the first operating mode. The increased rate of water supplied during the second operating mode reduces nitrous oxide emissions from gas turbine engine **10**.

In an alternative embodiment, when gas turbine engine **10** is operated above 90% rated engine operating capacity, steam is added to the fuel upstream from combustor **16**. In a further embodiment, steam is added to the fuel upstream from combustor **16** when the gas turbine engine is operated above idle power operations. The steam/fuel mixture is supplied only to combustor middle dome **64** because outer and inner dome flame temperatures are limited by dynamic pressure or acoustic boundaries. The steam/fuel mixture is heated prior to being introduced to middle dome **64** to prevent condensation from forming and is mixed thoroughly prior to be injected into combustor middle dome **64**. Additional steam permits flame temperatures generated within middle dome **64** to be maintained approximately equal that of flame temperatures generated within outer and inner domes **58** and **70**. As a result, nitrous oxide emissions generated within middle dome **64** are maintained at a level approximately equal to those levels generated within outer and inner domes **58** and **70**. Furthermore, because additional steam is supplied only to middle dome **64**, the potential adverse effects of additional carbon monoxide emissions generated within combustor **16** are offset by the reduction in nitrous oxide emissions and the increase in engine operating capacity.

The above-described combustor system for a gas turbine engine is cost-effective and reliable. The combustor system includes a combustor operable with a fuel/air mixture equivalence ratio less than one and a water delivery system that injects water and/or steam into the combustor to reduce nitrous oxide emissions generated during gas turbine engine operations. As a result, nitrous oxide emissions for specified turbine operating power levels are lowered. Alternatively, the operating power level of the gas turbine engine may be increased for a specified nitrous oxide emission level.

While the invention has been described in terms of various specific embodiments, those skilled in the art will recognize that the invention can be practiced with modification within the spirit and scope of the claims.

What is claimed is:

1. A method for operating a gas turbine combustor of a gas turbine engine using a water delivery system, the combustor including a plurality of domes, the water delivery system connected to the gas turbine engine, said method comprising the steps of:

supplying at least one combustor dome with a fuel/air mixture equivalence ratio less than one; and separately supplying at least one of water and steam into the gas turbine engine with the water delivery system such that at least one of atomized water and steam is separately injected into the combustor through an orifice in a fuel/air premixer centerbody such that the fuel/air mixture and the at least one of atomized water and steam are only mixed downstream from the centerbody wherein the orifice extends through the centerbody substantially coincident with a longitudinal axis of the centerbody.

2. A method in accordance with claim **1** wherein said step of supplying at least one of water and steam further comprising the step of supplying at least one of water and steam to at least one of the plurality of domes.

3. A method in accordance with claim **1** wherein the combustor includes a first dome, a second dome, and a third dome, the second dome disposed radially inward from the first dome and the third dome, said step of supplying at least one of water and steam further comprises the step of supplying at least one of water and steam to the combustor second dome.

4. A method in accordance with claim **1** wherein the combustor includes at least one dual fuel nozzle, said step of supplying at least one of water and steam further comprises the step of supplying at least one of water and steam to the combustor through at least one dual fuel nozzle.

5. A method in accordance with claim **1** wherein the gas turbine engine has a rated engine operating capability, said step of supplying at least one of water and steam further comprises the step of supplying at least one of water and steam to the gas turbine engine when the engine is operating at an operating speed greater than approximately 90 percent rated engine power capability.

6. A combustor system for a gas turbine engine, said combustor system comprising: a combustor comprising a plurality of domes, at least one of said combustor domes configured to operate with a fuel/air mixture equivalence ratio less than one; and a water delivery sub-system connected to the gas turbine engine and configured to separately supply at least one of water and steam to the gas turbine such that at least one of atomized water and steam is separately injected into the combustor through an orifice in a fuel/air premixer centerbody such that the fuel/air mixture and the at least one of atomized water and steam are only mixed downstream from the centerbody wherein the orifice extends through the centerbody substantially coincident with a longitudinal axis of the centerbody.

7. A combustor system in accordance with claim **6** wherein said water delivery sub-system further configured to supply at least one of water and steam to at least one dome of said combustor.

8. A combustor system in accordance with claim **7** wherein said combustor further comprises at least one dual fuel nozzle, said water delivery sub-system further configured to supply at least one of water and steam to said combustor through at least one dual fuel nozzle.

9. A combustor system in accordance with claim **7** wherein said combustor further comprises at least one premixer in flow communication with said water delivery sub-system.

10. A combustor system in accordance with claim **6** wherein said combustor comprises a first dome, a second dome, and a third dome, said second dome disposed between said first and third domes, said water delivery sub-system further configured to supply at least one of water and steam to said combustor second dome.

11. A combustor system in accordance with claim **6** wherein said water delivery sub-system selectively operable in a first mode and a second mode, said water delivery sub-system further configured to supply water to said combustor at a first flow rate when in the first operating mode, said water delivery sub-system further configured to supply water to said combustor at a higher flow rate when in the second operating mode.

12. A combustor system in accordance with claim **11** wherein the engine has a rated engine power, said water delivery sub-system is further configured to supply water in the first operating mode when the gas turbine engine operates below a predefined percentage of the rated engine power and supply water in the second operating mode when the gas turbine engine operates above the predefined percentage of the rated engine power.

13. A gas turbine engine comprising a combustor system comprising a combustor and a water delivery sub-system, said combustor being a lean premix combustor comprising a plurality of domes, at least one of said domes configured to operate with a fuel/air mixture equivalence ratio less than one, said water delivery sub-system configured to separately supply at least one of water and steam to the gas turbine engine such that at least one of atomized water and steam is separately injected into the combustor through an orifice in a fuel/air premixer centerbody such that the fuel/air mixture and the at least one of atomized water and steam are only mixed downstream from the centerbody wherein the orifice extends through the centerbody substantially coincident with a longitudinal axis of the centerbody.

14. A gas turbine engine in accordance with claim **13** wherein said combustor comprises at least one premixer, said water delivery sub-system further configured to supply at least one of water and steam to at least one premixer of said combustor.

15. A gas turbine engine in accordance with claim **13** wherein said water delivery sub-system further configured to supply at least one of water and steam to at least one dome of said combustor.

16. A gas turbine engine in accordance with claim **15** wherein said combustor further comprises a first dome, a second dome, and a third dome, said second dome disposed between said first and third domes, said water delivery sub-system further configured to supply at least one of water and steam to said combustor second dome.

17. A gas turbine engine in accordance with claim **13** wherein said water delivery sub-system selectively operable in a first mode and a second mode, said water delivery sub-system further configured to supply water to said combustor at a first flow rate when in the first operating mode, said water delivery sub-system further configured to supply water to said combustor at a higher flow rate when in the second operating mode.

18. A gas turbine engine in accordance with claim **17** wherein said gas turbine engine has a rated engine power capability, said water delivery sub-system further configured to supply water in the first operating mode when the gas turbine engine operates below a predefined percentage of the rated engine power and supply water in the second operating mode when the gas turbine engine operates above the predefined percentage of the rated engine power.

19. A gas turbine engine in accordance **18** wherein said water delivery sub-system further configured to supply water in the second operating mode when said gas turbine engine is operating at an operating speed greater than approximately 90 percent rated engine power capability.

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